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5. Snow and Ice Research in Canada (C.S.L. Ommanney, International Commission on Snow & Ice, National Hydrology Research Institute, Saskatoon).

The International Commission on Snow and Ice (ICSI) is interested in all aspects of glaciology, or the science of snow and ice, including ice in the atmosphere, glaciers, floating ice on lakes and rivers, sea ice, snow, permafrost and ice in the ground. Although ICSI now is part of IAHS, its interests and activities extend well beyond the traditional bounds of hydrology. Thus a report limited to hydrology will omit many ICSI activities, may deal inadequately with others and will likely overlap with reports from some related Commissions. In 1987, the Subcommittee on Glaciers was instructed by ACH to include their annual report with that of the ICSI Correspondent. Thus the long tradition of a separate report on glaciers in the Canadian Geophysical Bulletin has regrettably been broken.

This report includes material which would have been published in the glacier research chapter. In addition, it covers floating lake and river ice, snow and permafrost to the extent that they may relate directly or indirectly to hydrology. It is based largely on recent publications and events; by next year an appropriate reporting structure should be in place.

A recent highlight for many Canadian glaciologists was the hosting of the IUGG in Vancouver with its special symposia. Symposia on the Physical Basis of Ice Sheet Modelling, Modelling Snowmelt-Induced Processes, Large-Scale Effects of Seasonal Snow Cover and the Influence of Climate Change and Variability on the Hydrologic Regime and Water Resources featured many Canadian contributions. 1987 was also the year the International Glaciological Society (IGS) celebrated its Anniversary by hosting a one-day session on the history of glaciology and a symposium on remote sensing in glaciology. Canadians have always played a very active role in this society and Clarke, currently Vice-President, and Gold, a past President, both presented review papers. These, and other reviews, make frequent reference to work by Canadians. The National Student Conference on Northern Studies, held in November, 1986 in Ottawa, reported activities that will likely be indicative of some research directions for the future.

(a) Glaciers

Another very significant glaciological meeting, held in Whistler Village, B.C., in May, 1986, was that on fast glacier flow. Organized by Clarke of UBC as an American Geophysical Union Chapman Conference, it brought to the forefront the question of the nature of the glacier bed itself and its influence on flow. The published proceedings include Clarke's paper on subglacial till.

(i) Arctic Current glacier research will be discussed in a geographical context. Much work is now being done on Ellesmere Island. The ice-core project on Agassiz Ice Cap, recently transferred from the Polar Continental Shelf Project to the Geological Survey of Canada, continues to contribute interesting results. Theoretical problems associated with the interpretation of cores from this area include the effects of wind pumping, by Clarke et al., and improved flow models by Reeh et al. Borgeois has investigated the pollen record. Fisher and Koerner have assessed the rheological properties of ancient ice laden with microparticles. The latter heads a team that is establishing a climate history for the High Arctic using the ice-core records from the Agassiz, Devon and Meighen Ice Caps. The mass and energy balance of two small ice caps near St. Patrick Bay was studied by Bradley and Serreze, University of Massachusetts. Along the north coast, Jeffries, now with the University of Alaska, is continuing work started at the University of Calgary on ice islands, ice shelves and associated glaciers. Holdsworth, with the National Hydrology Research Institute (NHRI), has contributed further to an understanding of their development. Stewart and Bednarski studied structures in Dagger Glacier; Brochu those associated with the surface of Gilman Glacier; and Fisher and Evans, University of Alberta, debris-entrainment and ice falls in the vicinity of Phillips Inlet.

Results continue to be published on work undertaken by scientists from ETH, ZUrich, on Axel Heiberg Island. Blatter found an interesting thermal regime in White Glacier and a stagnant ice body at its bed. Data from this glacier were used in a Soviet study by Kaser on the role of evaporation in mass balance.

Koerner continued to monitor mass balance at a number of High Arctic sites and proposed a technique for using glaciers as "climatometers". A resurvey of Meighen Ice Cap by Haythornthwaite shows a slight thickening in the centre when compared to the 1960 levels.

On Baffin Island, the Barnes Ice Cap work has now drawn to a close. Hooke et al. (University of Minnesota), Hanson and Dickinson, and Stolle and Killeavy have reported the latest mass balance data and the results of some theoretical studies. Dowdeswell, from Cambridge University, completed a study of tidewater-glacier sediments in Frobisher Bay using an outlet from the Grinnell Ice Cap.

(ii) Yukon Territory Another major palaeo-glaciological investigation is being carried out by Holdsworth using ice cores from the top of Mount Logan (YT). Reports have been published on some trace acid results and those relating to links with atmospheric nuclear testing. Recent analysis revealed a striking correlation between the precipitation record here and for parts of the Soviet Union, which is being investigated further. Johnson and University of Ottawa students are studying debris-covered and rock glaciers in the Dalton Range. He and Kasper looked at the drainage characteristics of a lake dammed by Kaskawulsh Glacier. To the north, Liverman has been studying sedimentation in ice-dammed Hazard Lake. Trapridge Glacier has been the primary focus of much of Clarke's work and one of his UBC students, Maxwell, has recently completed an assessment of the use of isotopes for studying subglacial processes.

Considerable public interest and comment was occasioned by the advance of Hubbard Glacier into Russell Fiord, its subsequent damming and the trapping of marine aquatic life. The glacier is one of many that rises in Canada and drains into Alaska. It appears to be undergoing a normal advance and will likely dam the fiord again.

(iii) Coast Mountains Studies in the Coast Mountains are now limited to Sentinel, Helm and Place Glaciers where Mokievsky-Zubok and Fogarasi (NHRI) have reported on recent mass balance results and an analysis of discharge data from Sentinel, and, to Wedgemount Glacier where Ricker, a consultant, and Tupper, BCIT, have continued mass balance and photogrammetric surveys. Pelto, U.S. Geological Survey (USGS), has recently been using remote sensing techniques to establish mass balance values for southeastern Alaska and northwest British Columbia; an area identified by Meier as being crucial in the assessment of the role of melting glaciers in the recent rise of sea level.

(iv) Interior Ranges In the Interior Ranges, Luckman and colleagues from the University of Western Ontario, including H.M. Watson, have reported glacier advances in the Premier Range. Luckman and McCarthy have done extensive field work in the area of Glacier National Park and in the Rockies around the Columbia Icefield and Mount Robson. Osborn, University of Calgary, has documented the Neoglacial history of Bugaboo Glacier.

(v) Rockies In the Rockies, NHRI continues mass balance observations at Peyto Glacier. Letreguilly analysed the record in relation to data from two neighbouring weather stations. Munro, University of Toronto, has initiated an energy balance study there. Leonard has been investigating sedimentary sequences in some of the neighbouring lakes. Around the Columbia Icefield, Gardner and Jones, University of Waterloo, have looked at debris transport and erosion at Boundary Glacier while Sloan, Trent University, has been investigating some of the melt processes. Trombley (USGS) completed a radio echo-sounding survey of the Athabasca Glacier and Smart (Western Ontario) reported on his karst hydrology study in the Castleguard area.

(vi) General The length of glacier mass-balance data records from a number of Canadian glaciers in the Cordillera and Arctic has resulted in their use in a variety of studies by international scientists. Recent ones include those by Konovalov, Kotlyakov and Shamin, Makarevich and Rotatayeva, Xie and Zhang, Ohmura et al., and Valdeyev. Ananicheva has reported on data reduction methodologies used for the World Atlas of Snow and Ice Resources.

Results of glacier mass balance in the Torngat Mountains, Labrador, some with rather unusual regimes, have now been published by Rogerson et al.

A long-standing analysis by Shoemaker, Simon Fraser Unl
versity, is now coming to a close with the publication of a number of theoretical papers on glacier-flow problems. An airborne UHF radar system, developed by Clarke at UBC, was used to measure ice depth and stratigraphy in the caldera of Mount Wrangell, Alaska.

(vii) Glacier Hazards The sudden drainage of a number of ice-dammed lakes in B.C., particularly Ape Lake, and some other glacier-related hazards led to studies by Clague, Evans, Gilbert and Desloges, Ricker and Ricker, and Jackson. Clarke recently paid tribute to the work of Mathews in this area.

(viii) Exploitation One interesting new development has been the exploitation of glaciers as a source of pure water. According to media reports, a company was formed in Alberta to mine glacier ice in the Front Ranges for sale in supermarkets. A similar proposal in British Columbia ran into difficulties when officials could not issue a licence because glacier ice was deemed to be neither a mineral nor a water resource. Other ventures in B.C. plan to export glacier melt water.

(b) Floating Ice on Rivers and Lakes

Most recent reports on lake and river ice are in the proceedings of the 4th Workshop on the Hydraulics of River Ice held in June, 1986 in Montreal and the 8th International IAHR Symposium on Ice, held in Iowa City the same month. Some appear in the proceedings of the Symposium on Cold Regions Hydrology, which took place a month later in Fairbanks, and those of the Eastern Snow Conference. Other have appeared in the scientific literature and as internal reports. Economic costs of lake and river ice problems, particularly those related to ice-jam flooding, can be assessed from newspapers. Gold, in his IGS anniversary review paper also alluded to some of these aspects.

(i) Quebec A major recent focus has been the St. Lawrence River in the vicinity of Montreal, lac St-Louis and the Lachine Rapids, particularly in connection with Projet Archipel and the development and testing of the RHIVER model. Much of the work has been done by Laval University under the direction of Michel and by the LaSalle Laboratories. Individuals involved have included Desroches, Fau, Fonseca, Hausser, Ho, Holder, Leclerc, LeVan, Parkinson, Petryk, Rivard, Saucet and Silver. Robert, Brochu and Robitaille have considered the problem of ice management at Beauharnois and Larouche, Tanguy and Tremblay have discussed ice jam flooding on the rivière du Nord and freeze-up and break-up on a number of northern Quebec rivers. Upstream from Montreal, Garrity et al. have been carrying out microwave experiments on the river ice over the past three winters.

(ii) Ontario In Ontario, much of the work also relates to flooding and operational problems. Beltaos and Wong (NWRI) have investigated ice jams and freeze-up and break-up processes on the Upper Grand River. Ice conditions on the Niagara River were studied by Churchill, and the International Niagara River Working Committee continues to observe the operation of its ice boom. Cumming-Cockburn and Associates were contracted by the Inland Waters Directorate (IWD) and the Government of Ontario to report on ice jams in the Credit River valley. Elsewhere, Burrell et al. have looked at break-up on the Meduxnekeag River. Jams in the St. Clair River influence Great Lakes' levels and this aspect is under investigation by Derecki and Quinn. Tsang (NWRI) is in the process of developing a frazil ice model. Unfortunately Hanley, another frazil-ice researcher, based at the University of Regina, passed away recently. An historical study of Red River flooding has recently been published by Bumstead.

(iii) Western Canada Alberta also has significant ice-jam flood problems, particularly in the vicinity of Fort McMurray on the Athabasca River. Research here is under the direction of the University of Alberta (U of A) and the Alberta Research Council and includes Andres, Flato, Gerard and Rickert. Loch, Kirchner and Simpson (U of A) are studying the potential of a thermosyphon system for influencing ice growth in the Peace River. Mercifully, B.C. seems fairly free of lake and river ice problems so there is little research on this being done there.

(iv) Territories In the Territories there are significant problems and interesting research possibilities. Alford (IWD) is investigating the ice cover and streamflow of the Yukon River, Whitfield and McNaughton the levels of oxygen under the ice, and Campbell, University of Manitoba, channel icings and their geomorphological effects. Along the Liard and Mackenzie Rivers, Prowse and Marsh (NHRI) have carried out a series of experiments on heat fluxes, break-up, ice jamming, the decay of ice jams and discharge measurements during break-up. S.A. Watson, Trent University, has assessed the use of aerial photographs for obtaining ice-jam measurements. The problems of break-up on small Subarctic rivers have been addressed by Woo and Heron at McMaster University.

(v) Atlantic Provinces River ice problems also exist in the Atlantic Provinces and those in New Brunswick, at Simonds, have been tackled by the provincial government while Davar and Hendrickson have looked at flow resistance in ice-covered channels using the Naskwaak River as an example.

(vi) Lake Ice Recent research on lake ice has taken a variety of directions. Adams and his colleagues from Trent University have been developing measuring techniques using a lake much as a snow pillow. Other studies have been on the chemical composition of the ice and water and the problem of acid shock. Students such as Allan and Doran have pursued this line of research on Colour Lake (Axel Heiberg Island), Knob Lake (Newfoundland) and Plastic Lake (Ontario). Anderson and Skinner (AES) and Barry and Maslanik, University of Colorado, have compiled information on freeze-up and break-up dates on lakes as indicators of climate change. In the Mackenzie Delta, Bigras (NHRI) has been assessing the influence of different river levels on a variety of Delta lakes. Operational considerations on the Great Lakes have led to studies of Lake Erie by the IWD in Canada and NOAA in the United States. Foulds has reported on the nature of the research problems, Agiroff and Weigum on matters pertaining to the extension of navigation on the Great Lakes and Greene and Campbell on lake ice dynamics.

(c) Permafrost

Although many universities, the Geological Survey of Canada and the NRCC Institute for Research in Construction have active permafrost research programs, much is geotechnical or geothermal rather than hydrological in orientation. French, Bennett and Hayley from Ottawa University have continued working on Banks and Melville Islands. Lewkowicz completed an investigation of ablation, slumping and thermokarst development, and Pollard one on frost mounds. At Carleton University, Smith and Michel, studying permafrost development in the Territories, are also looking at implications of climate change. Burn's work on aggradational ice was finished and Williams reissued his book on pipelines and permafrost. McGill University published an index of permafrost data in the Schefferville area where Granberg, Wright, Moore, Desrochers and Kingsbury have reported

on active layer development, thermal regimes and other studies. Largely through the Centre d'Etudes Nordiques, Université Laval has been involved in the Nouveau-Québec and Hudson Bay areas through the work of Allard, Seguin, Levesque and Pelletier. The interest at McMaster University has been in effects on karst (Ford), active layer development (Halliwell) and hydrology (Roulet and Woo). Mackay at UBC continues his work on pingos and the investigations at Illisarvik. High-altitude permafrost and climate change in Yukon is the subject of research by Harris, University of Calgary, who has just published a book on permafrost. Young (Waterloo) is studying the distribution and thickness of permafrost, Leclerc (Sherbrooke) permafrost found in Mayo, Marsh (NHRI) run-off from it in the Mackenzie Valley and Obradovic (Windsor) the role of permafrost run-off in the Apex River, Baffin Island. Finally, Van Everdingen with the Arctic Institute of North America is looking at broad aspects of the hydrological regime of permafrost and Allan et al. (Trent) the influence of solifluction on chemistry.

(d) Snow

Broad, regional studies of the snow cover of Canada by Dewey, Goodison et al. (AES), Morinaga and Yasunari, Walsh and Wiesnet are included in the proceedings of the IAHS Symposium on Large Scale Effects of Seasonal Snow Cover. These consider snow cover/atmosphere interactions and the impact of the seasonal snow cover. Much more comprehensive coverage at this scale is provided in Snow Watch '85 through the reports of Baldwin, Barry, Chang, Dewey and Heim, Goodison, Matson, Robinson, Roback and Scialdone, and Ropelewski. These reports generally deal with satellite-derived snow-cover data. Goodison, Goodison et al. and Kind continued the national perspective with their papers on snow surveying and drifting in the recently-published proceedings of the Snow Property Measurement Workshop. The IAHS Symposium on Modelling Snowmelt-Induced Processes included an initial report on the WMO intercomparison of snow-melt run-off models, which used the UBC and CEQUEAU models from Canada, and the final report should now be available. Cavadias and Morin have also commented on this work. A major meeting on Snow Management for Agriculture will be discussed below in the context of Prairie studies. AES continues to collect and publish snow data. These, together with other sources, were used by Ivanovskaya and Kravchenko in a study of the North American snow cover. Harvey, University of Toronto, developed explicit snow balances for his three-level energy balance climate model. Goodison and Louie have continued their discussion about the correction of Canadian snow data.

(i) Atlantic Provinces In the Maritimes, Daugharty and Dickinson of the University of New Brunswick continue their research in the Naskwaak River basin (N.B.) on the effects of the forest cover. The Saint John River basin, the target of a number of remote-sensing experiments over the years, was studied by Haas (NHRI) using ground and airborne snow surveys, and its headwaters by Merry and Miller, Cold Regions Engineering and Research Laboratory, using Landsat digital data. Snow data for the basin are provided by the province through a cooperative snow survey project. In Kejimkujik National Park, Roussel and Clair (IWD) have investigated the chemical and physical characteristics of the snow cover.

(ii) Quebec Research on snow in the Province of Quebec is led by McGill University and INRS-Eau of the Université du Québec à Québec. At the latter, H.G. Jones and his colleagues including Bédard, Deblois, Sochanska, Stein, Roberge, Plamondon and Charette, some from Université Laval, have worked on the chemistry of snow in the lac Laflamme basin. Jones organized a recent NATO Advanced Studies Institute on the physics, chemistry and hydrology of the seasonal snowcover. McGill's research area is Schefferville where Granberg and Moore, together with Desrochers, Wener, Kingsbury, Kulkarni and Nadeau have investigated the energy balance and stratification of snow.

(iii) Ontario In Ontario, pollution of snow by acids and road salt is being investigated by scientists from a variety of institutions, including AES and McMaster and Guelph Universities. They include Goodison, Louie, Metcalfe, Drake, Vermette, Landsberger, Simsons, Whiteley, Pakala, Schroeter, Hendershot, Dufresne, Lalande, Corchesne, Pilon, Howard, Thompson, Blackwood and Davies. The matter of winter storm tracks is being addressed by Stewart and McFarquhar (AES) in their studies of the rain/snow boundary. The energy balance of urban and forest snow covers has been measured by Adams, Lafleur, Xu and Buttle from Trent University and Woo and Steer (McMaster) have also considered the latter. Bottomley, Craig and Johnston (NHRI) used isotopes to monitor snowmelt run-off. Spatial distribution of snowmelt run-off for a number of basins is the object of research at McMaster by Irvine and Drake and for the Great Lakes basin by Hartmann and Croley.

(iv) Prairies The subject of snow research in the Prairies benefitted greatly from the recent meeting on Snow Management for Agriculture. The proceedings, edited by Steppuhn (Agriculture Canada) and Nicholaichuk (NHRI), catalogue a variety of swathing, tilling, cropping and other agricultural management practices designed to enhance soil moisture through efficient trapping and utilization of the snow cover. Researchers were drawn from Agriculture Canada, various Prairies universities, other government laboratories including NHRI and from the farming community. Another symposium, held to commemorate the opening of the National Hydrology Research Institute in Saskatoon, identified techniques for more efficient use of the available snow cover as an appropriate focus for some of the research programs. The same theme has been repeated by Gray, Granger, Landine, Pomeroy and others from the University of Saskatchewan in a variety of recent papers and again by Nicholaichuk and Steppuhn. The large flat expanses of the Prairies are ideal for remote sensing. Microwave radiometry experiments by Goodison et al. were reported in Vancouver, as was the integration of digital terrain models with snow and runoff measurements by Whiting and Kiss of the Saskatchewan Research Council. Problems of precipitation and its measurement have been considered by K.H. Jones (AES) and techniques for augmenting it through cloud seeding by Robitaille, Barlow and Reineck of the Alberta Research Council (ARC) and U of A.

(v) Cordillera In the Cordillera, snow problems are slightly different. The relationship between timber-harvesting techniques and snow melt run-off has been the object of a long-standing research project in Marmot Creek, Alberta. Golding (UBC), Bernier, Nip and Swanson (Alberta Forest Service) have reported some results from here, Toews and Guns for parts of southeastern B.C., and Beaudry and Golding from Jamieson Creek (B.C.). Remote sensing has been applied to the assessment of the snow cover in some areas of the Cordillera: Sargent, Gardner and Howarth (Waterloo) in the eastern Rockies, and Sutherland and Ferner (Alberta Environment) in the headwaters of the Bow River. Thyer (U of C), Barlow and Robitaille have analysed winter precipitation, snow cover and atmospheric conditions in the southern Rockies. Provincial and federal agencies continued to monitor the snow cover in this area and to publish the results of the snow surveys. Coles et al. (Alberta Environment) have discussed their experience in operating snow pillows in the mountains of Alberta. In central B.C., the Illecillewaet River was the object of tests by Quick and Pipes (UBC) designed to improve their model. With Calgary hosting the Winter Olympics, there were a number of contracted studies reporting on past and expected snow and weather conditions at the various event venues. Some controversy was raised over the proposed use of bacteria in the snow making machines, and this received fairly extensive coverage in the newspapers despite assurances from officials that the bacteria was harmless.

(vi) Northwest Territories: In the Northwest Territories, a regional study on the July residual snow cover in the Arctic was completed by Lauriol et al. (Ottawa). Barry (University of Colorado), at a conference on the impact of climate change on the Arctic, considered the impact of a climate warming on snow and ice in the area. Marsh (NHRI), Woo and Heron (McMaster) have been investigating grain growth, heat flux and discharge in a basin on Cornwallis Island. Isotope variations in snow along the north coast of Ellesmere Island were measured by Jeffries and Krouse (University of Calgary) and those in the small Apex River watershed on Baffin island by Obradovic and Sklash (Windsor). The Department of Indian and Northern Affairs publishes the results of snow surveys.

(e) Snow Properties

Comparatively little work is being done on some of the fundamental properties of snow which may be critical for the proper evaluation of remotely-sensed signals. The leading Canadian researcher in this area is Perla (NHRI) who, with colleagues from the United States, has developed a dilution method for measuring liquid water in snow, techniques for the preparation of serial sections of dry snow specimens and for the study of microstructure using stereology, and has reported on the metamorphism, morphology, and microstructure of snow as well as its permeability. The problems of snow drifting have been addressed by Pomeroy, Brown and Male (U. Sask.) who have measured blowing snow properties with optical attenuation devices, modelled it for agricultural production and assessed the wind transport of seasonal snowcovers in the Prairies. The remaining investigations into physical properties of the snow cover have been sponsored by the military. Granberg (McGill) has developed a computerized snow information system for military field operations. Fukue and Yong (McGill) studied the mechanical and physical properties of snow and completed an energy analysis of its confined compression and shear behaviour. Hutt and Shirkey (DND) have verified certain snow transmittance predictions and Irwin (DND) has investigated index measurements in studies of snow under vertical loading. These latter studies relate more to questions of traffic-ability than to hydrology.

(f) Concluding Remarks

Although this review might seem to indicate that glaciological research is flourishing in Canada, most of those involved would not agree. If one considers that Canada is snow-bound for almost six months of the year, that the country has more glaciers than any other in the world (excluding Geeenland and Antarctica) and is probably second only to the Soviet Union in the extent and size of its ice-covered lakes and rivers, then our present research effort has to be considered an absolute minimum. Ice and snow will be among the elements most immediately affected by any warming in climate. Glaciers in the Front Ranges may disappear completely and eliminate much of the late-summer streamflow that helps sustain agriculture in the Prairies. Degradation of permafrost may result in significant and widespread changes in the hydrological regime of the north, due to a deeper, and possibly more mobile, active layer. Reduced sea-ice cover in the Arctic could compound any climatic change. We may be able to reasonably assume such consequences, but our knowledge of the fundamental processes, required for accurately modelling such changes, is still inadequate.

6. Water Quality

Research Needs for Canadian Water Quality Guidelines
(Extracted from February 1987 report "Research Needs for Canadian Water Quality Guidelines" prepared by the CCREM Task Force on Water Quality Guidelines)

The first edition of the "Canadian Water Quality Guidelines" was presented to the Canadian Council of Resource and Environment Ministers by its Task Force on Water Quality Guidelines in October, 1986 and was approved for publication (CCREM 1986). An ancillary project of the Task Force was to make recommendations on research priorities required to address deficiencies identified during the preparation of the report.

Water quality guidelines provide scientific information about the effects of water quality parameters on water uses. Guidelines are used to assess water quality issues and to establish water quality objectives for specific sites. Water quality issues, however, are difficult to assess for a number of reasons, the primary being a lack of appreciation of the dynamic complexity of the aquatic environment itself, including the interactions among physical, chemical and biological components. Superimposed upon this complexity are the social and economic constraints confronting the effective management of water quality. Although water quality guidelines, per se, are not always able to address these complex issues completely, they do, nevertheless, contribute to the judicious use of water resources. They provide an essential component in the water quality assessment process. As such, they are used to formulate site-specific water quality objectives which are, in turn, used to provide a basis for protecting water uses, to determine effluent limits and other regulations on activities affecting water quality, and to identify water quality problems. Scientific criteria that are based on research that quantifies cause and effect relationships provide the essential foundation for the development of water quality guidelines and, in turn, the effectiveness of water quality management programs. Hence, it is critical that research provides scientific data appropriate to the development and use of sound water quality guidelines. During the development of the first edition of the Canadian Water Quality Guidelines a number of deficiencies were identified. These deficiencies focused primarily on scientific data gaps which prevented the recommendation of a guideline, or only allowed for the proposal of a tentative guideline. It must be recognized that the identification of and action on scientific data gaps for guideline development is only one need among various research, data, management, and socio-economic needs requiring consideration in the overall assessment of water quality issues.

The Task Force on Water Quality Guidelines considers that the following specific research is of high priority for the further development of Canadian Water Quality guidelines.

(i) Raw Water for Drinking Water Supply Improved methodologies are needed for the identification of organic chemicals that are found in drinking water sources and are a health concern. The possible formation of toxic substances during water treatment and the removal efficiency of various water treatment practices require investigation.

(ii) Recreational Water Quality and Aesthetics There is a high priority for research on new microbial indicators and studies relating these to disease incidence during recreational activities. Epidemiological studies should be conducted so that health risks can be quantified.

(iii) Freshwater Aquatic Life The use of aquatic organisms relevant to Canadian conditions in the development of appropriate water quality guidelines is of high priority, not only on a national but also on a regional scale. Studies on the bioavailability of toxic substances to aquatic organisms, as well as studies on the persistence of toxic contaminants, should be encouraged. The ecological significance of residues of persistent substances in the aquatic environment warrants further attention. Information about water quality and resident biota in the northern aquatic environment must be obtained so that appropriate water quality guidelines for northern regions can be developed. Many water quality guidelines are based on extrapolations of data obtained from acute toxicity tests in order to estimate safe levels. The use of application factors in aquatic toxicology, however, remains controversial, and increased efforts are required to identify alternative, cost-effective methods for estimating hazards to aquatic biota. The first edition of the Canadian Water Quality Guidelines does not contain recommendations for phosphorus; the scientific data base for phosphorus in aquatic systems, particularly in riverine systems, should be reviewed to determine whether sufficient information is available to recommend appropriate guidelines for waters other than the Great Lakes. Research on the fate and effects of pesticides in modern agricultural usage is required so that relevant water quality guidelines can be developed where needed. The Task Force on Water Quality Guidelines considers that high priority should be assigned to the specific studies for the following water quality parameters: chlorine, copper, zinc, cadmium, dissolved oxygen, aluminum, mercury, chlorophenoxy compounds, polychlorinated biphenyls, polynuclear aromatic hydrocarbons, chlorinated phenols, and phthalate esters.

(iv) Agricultural Uses Research on the fate and effects of toxic substances associated with Canadian agricultural practices has a high priority. The biological availability of these substances in irrigation water and livestock drinking water requires attention. In addition, the impact upon other water uses of irrigation return-flow waters warrants study. Needs for research on specific water quality parameters in agricultural waters include studies on pathogens in irrigation and livestock drinking water, aluminum in irrigation water, herbicides in irrigation water, and pesticides in livestock drinking water.

7. Remote Sensing and Data Transmission (J. Whiting, International Committee on Remote Sensing and Data Transmission, Saskatchewan Research Council).

(a) Remote Sensing

Environment Canada's, Inland Waters Directorate received two reports from A.J. Robinson & Associates on the Study of Methodologies of Streamflow Forecasting Incorporating Remotely Sensed Data. The first was a literature review. The second focussed on the implementation of operational remote sensing techniques in a streamflow forecasting model (the SSARR model). The techniques interfaced were snow cover extent

using density sliding and digital techniques, snowpack water equivalent combining airborne gamma-ray flight surveys with snow course data, and land cover using a pseudo-digital technique. The study area was a tributary of the Saint John Basin.

Alberta Environment continued their demonstration study assessing the utility of computer processed NOAA imagery for snow cover mapping and streamflow simulation using the SSARR model. Lack of resources could limit operational implementation.

The Hydrometeorology and Marine Division of Environment Canada's, Atmospheric Environment Service (AES) has been carrying out a study to evaluate the ability of three satellite rainfall estimation techniques to derive daily, weekly and monthly precipitation estimates under Canadian conditions. The study includes investigation of the applicability of various objective analysis schemes for interpolating precipitation data to a regular grid. The Division also conducted research on the determination of snow cover water equivalent using passive microwave radiometry. Contract support to the private sector allowed for steady progress in the development and testing of algorithms for determining snow cover properties from passive microwave satellite data.

Dr. N. Kowwen of the University of Waterloo has developed a micro-computer-based, distributed rainfall-runoff model which can incorporate ground-based radar precipitation data and other remotely-sensed input. The model has excellent potential for flash flood forecasting purposes.

(b) New Initiatives

The Hydrometeorology and Marine Division (AES) contracted with PhD Associates for the development of a turn-key micro-based passive microwave image analysis system. The interactive system will use NIMBUS-7 SMMR or DMSP SSM/I data formatted on floppy disk.

Saskatchewan Research Council initiated a joint study with AES (Saskatoon, National Hydrology Research Institute (NHRC)) on "The design of a western Canadian real-time system for integrated forecasting of basin specific floods and low flows". The study includes an examination of the use of remote sensing in integrated forecasting.

An interagency working group involving members of the Canadian Advisory Committee on Remote Sensing (CACRS) Water Resources Working Group developed plans for the Prairie snow cover passive, microwave validation experiment. The DMSP SSM/I was launched in 1987. A mini-program of ground and airborne snow data collection was collected in the winter of 1987 in preparation for the main 1988 experiment.

The Canada Centre for Remote Sensing (CCRS), in cooperation with Environment Canada, contracted with the University of Quebec (INRS-Eau) to produce, in 1988, a prototype of a micro-computer-based, distributed hydrologic model designed to make direct use of remotely-sensed data. The various modules comprising the model have been under development by INRS-Eau over the past several years.

(c) Data Transmission

Canada currently operates 678 Data Collection Platforms (DCP's) on the U.S.A. NOAA GOES satellite. The exact number operating on the French ARGOS system is not currently available but is estimated to be about 60 stations (the majority are floating buoys). The largest user is the Water Survey of Canada with 334 active sites with another 45 about to be installed. Of these, 53 are read by multiple users. Table 2 is provided to give an indication of the diversity of users and the types of station operated.

The majority of stations in Canada are used for flow and flood forecasting with some used for water quality, reservoir operation, and river navigation. Most stations are now frequency-agile to allow for station movement across Canada.

There is an effort to move the entire system to an operational mode from the present historic data collection and research environment. As part of this shift many stations are being fitted with meteorological and water quality sensors to fulfill a dual role for other agencies.

Research is currently being carried out by Water Survey on providing information on ice conditions, break-up and jamming using DCP's.

TABLE 2: Canadian Users of Data Collection Platforms (DCP's)

	ST	I	INT'L	RR	ACT
Alberta Environment.....	45				39
Alberta Forest Service.....	5				4
Atmospheric Environment Service.....	58				53
British Columbia Hydro Authority.....	81				72
British Columbia, Ministry of Transportation.....	2				1
British Columbia, Min. of Water Mgmt...	6				6
Bristol Aerospace.....	1			1	1
Canadian Institute of Ocean Sciences...		1			
anadian Marine Environmental Data Services.....	9				4
Canadian "ASAP" Program (NWCASP).....			4		3
ESSO Resources Ltd.....	2				
Ministère de l'Environnement, Québec...	148				132
Ontario Hydro.....	20				19
Ontario Ministry of Natural Resources..	13				8
Petro Canada Exploration Inc.....	6				
Saskatchewan Research Council.....	2				1
University of Calgary.....	1			1	1
Water Survey of Canada.....	389	—	—	3	334
Total Canada	788	1	4	5	678

Note: St-Self Times; I-Interrogated; Int'l-International; RR-Random Reporting; ACT-Active.

8. Report from the Associate Committee on Hydrology

The National Research Council's Associate Committee on Hydrology (ACH) brings together hydrology researchers and managers from federal and provincial governments, universities and professional societies to advise on research priorities and on the application of hydrologic knowledge to Canadian water management. The Committee has three administrative subcommittees; International Affairs, Research Priorities and Dissemination of Knowledge and two technical subcommittees; Glaciers and Hydraulics of Ice Covered Rivers.

The 1987 National Lecture Tour co-sponsored by CWRA was conducted by Dr. R.H. Swanson, Canadian Forestry Service, who gave the audience a choice of three topics - (1) Measuring Transpiration of Trees, (2) WRENSS - A Model-Based Procedure for Estimating the Annual Water Yield from Forested and Partially Forested Catchments and (3) Canadian Research Basins. A video of the lecture was made and this procedure will be recommended for future tours.

In August, 1987 the ACH, as Canadian National Committee for the International Association of Hydrological Sciences, was responsible for organizing five symposia and eight workshops for the IAHS/IUGG General Assembly in Vancouver. The proceedings of the five symposia were pre-published and are available from IAHS offices. Proceedings of some of the workshops will be published either as separate volumes or in the Hydrological Sciences Journal. During the Assembly Canada was honoured to have five Canadians elected as officers to IAHS and its Commissions for the period 1987-1991. Dr. V. Klemes of Environment Canada's National Hydrology Research Institute is the new President of IAHS.

As the Canadian National Committee for the Unesco IHP, ACH is preparing an evaluation of the existing IHP III (1984-1989) and the proposed IHP IV (1990-1995) programs. For IHP IV, entitled "Water Resources for Sustainable Development in a Changing Environment", Canada is proposing to take a lead role in four of the 39 projects. ACH has proposed Canada as the representative for Western Europe and North America on the IHP Bureau. Elections will take place in June, 1988. Canada is already a member of the Intergovernmental Council.

Publications and Papers: (for copies or further information call D. Greene ((819) 953-1507)

- "Hydrologist"; a career brochure
- "International Organizations with Water Resource Interests".
- "1985 Bibliography on Hydrology".
- "Hydrology of Floods in Canada" (available in 1988).
- "The Status of Water Resource Education in Canadian Universities"; a paper to be presented at the ACH sponsored Education and Training Session of the 6th IWRA Congress, Ottawa, May, 1988.
- State-of-the-art review papers produced by the ACH Subcommittee on Research Priorities include; Dryland Salinity; Organic Contaminants; Water Demand Management; Glacier Mass Balance; Hydrology Aspects of Drought.

9. Report from Environment Canada

(a) Federal Water Policy

The major initiative in 1987, a response to the numerous recommendations of the 1984-85 Inquiry on Federal Water Policy, was the tabling in Parliament on November 5 of the new Federal Water Policy. The policy statement consists of two goals and five strategies, with water quality protection and realistic pricing and valuation of water as the dominant themes. The policy is applied to 25 areas of concern, including drinking water protection, diversion and export, interjurisdictional issues, climate change and research needs. The range of concerns is not intended to be exhaustive, and the policies will evolve in response to changing conditions. The report on Federal Water Policy is available free from Environment Canada in Ottawa.

The involvement of the provinces in the consultative process during the development of the Federal Water Policy and discussion through the Water Advisory Committee of the Canadian Council of Resource and Environment Members has prompted several provinces to examine their legislative base and policy frameworks in relation to water management. It is expected that joint federal/provincial policy statements in specific water areas will emerge in the not-too-distant future. The development of a Canadian Water Policy is probably still a few years away.

The Federal Government is proceeding with two initiatives to update its water and environmental management capabilities in support of the new Federal Water Policy.

The Canadian Environmental Protection Act has been mentioned in the above report for Environment Canada and is expected to be passed in 1988.

The Federal Government is also reviewing existing legislation with a view to improving its response to international and interprovincial water issues. Specific attention is being directed to water export, both to prohibit large-scale diversions of water into the United States and to regulate small containerized shipments in collaboration with provinces; also to the current vacuum in Canadian legislation for resolving conflicts between provinces/territories on interprovincial rivers. One possible vehicle for consolidating federal approaches to such issues would be an amended Canada Water Act.

(b) Federal/Provincial Agreements

During the 1987-88 fiscal year two new federal-provincial water management agreements were concluded by the Minister of the Environment. The first of these was a Canada-Prince Edward Island Work-Sharing Arrangement which will identify future development potential in the province's water resource bases--groundwater, surface water, and estuaries (each party contributes up to $500,000 over three years). The other was a Canada-British Columbia Floodplain Mapping Agreement (each party contributes up to $2,500,000 over five years). Policies under the agreement

extend until 1998.

(c) Streamflow and extreme events in Canada in 1987

Streamflows in Canada throughout 1987 were, in general, in the below normal to normal range.

Winter flows on the east coast were below normal at 30 to 50 percent of median flow while the rest of Canada generally had flows in the normal range.

Spring flows were generally normal throughout central Canada. Parts of eastern Canada and western Canada experienced above normal flows. In eastern Canada, areas that had below normal flows at 20 to 50 percent of median in late winter had above normal flows and flooding in the early spring. For instance, in Central Newfoundland, the Gander River at Big Chute, (drainage area 4400 km^2) recorded a monthly mean discharge of 522 m^3/s at 261 percent of median flow that was the highest on record for April since 1949.

Heavy rains beginning March 30 and falling on a higher-than-normal snow pack caused flooding in the Perth-Andover, New Brunswick area and in the Beauce area of Quebec. Some 2000 people fled their homes along the St. John River as ice jams sent the water through the streets and into basements. The flooding caused millions of dollars in damage, including the collapse of a railway bridge and damage to a hospital. At the same time, in the Beauce region south of Quebec City, Quebec, hundreds of people were evacuated and thousands of homes were cut off from electricity. Damage, estimated at more than ten million dollars, was caused by rivers swollen by rain and spring runoff combined with ice jams on the rivers. At Ste-Anne-de-la-Perade, between Trois Rivières and Quebec City, a large railway bridge was swept away by huge blocks of ice carried down the flooding St. Anne River. In the region of Charlevoix stretching 200 kilometres from Quebec City east to La Malbaie, an estimated two million dollars in damages, mainly to roads, and to several homes, was caused by landslides brought on by the heavy rain.

The areas that had below normal winter flows in eastern Canada continued to experience, with the exception of spring runoff, below normal flows from spring to early fall. With almost drought-like conditions being experienced throughout this period, there were shortages of water for agriculture and municipal purposes. In rural areas, wells dried up, forest fires were difficult to bring under control and streams were extremely low. For instance, in western Newfoundland, the Upper Humber River near Reidville (drainage area 2110 km^2) recorded in August a mean monthly flow of 4.07 m^3/s that was 9 percent of the long term median flow.

Across Canada from New Brunswick to British Columbia, hot dry weather in April and May set the conditions for below normal runoff and the occurrence of numerous forest fires. More than 100,000 hectares of forest were burned and millions of dollars of private property and prime timber destroyed.

Throughout the summer in central and western Canada, unsettled weather conditions resulted in the development of severe storm systems and local heavy precipitation causing local heavy flooding. On July 14, severe thunderstorms lashed the Montreal area of Quebec for two hours and resulted in flooded streets and homes, uprooted trees, left two men dead and caused an estimated one hundred million dollars in property damage. The storm dumped 57 millimetres of rain in two and one-half hours.

On July 31 a tornado ripped through the Edmonton, Alberta area and left a 40 kilometre path of destruction as much as one kilometre wide. The tornado, with winds of up to 330 kilometres per hour, killed 27 people, left 100 families homeless and caused over 250 million dollars in property damage.

A major storm struck southwestern Manitoba and the city of Winnipeg on August 14. Rainfall amounts of up to 200 mm occurred. Flood and crop damages were high. Five traffic deaths in southern Manitoba were attributed to rain drenched roads.

In northwestern Alberta, between 12:00 hours July 30 and 06:00 hours August 2, 293 mm of rain fell in the headwaters of the Simotte River and 228 mm in the Keg River area. Extensive flood damage, estimated at six to ten million dollars, was caused to bridges, roads, crops and campsites.

The fall to early winter period across Canada had variable flows. The east coast had generally normal flows with pockets of below normal and above normal flows. No records were set. Central Canada had normal flows. The west coast had variable flow conditions. Southern British

Columbia had below normal flows at 50 to 80 percent of median which began in June and continued to December. The Fraser River at Hope (drainage area 217,000 km^2) recorded in October a daily mean flow of 744 m^3/s that was the lowest since records began in 1912. The central interior of B.C. experienced very dry fall conditions with many new low records established. Concerns for a good recovery for the 1988 irrigation season were expressed. Meanwhile northern British Columbia had above normal flows; however no records were set.

10. Bibliography

The 1985 Bibliography of hydrology produced by WATDOC from the AQUAREF database was published as special edition volume 12, number 2 of the Associate Committee on Hydrology's newsletter Hydrological Events. (For a free copy contact G.A.D. Greene, 819-953-1507).

The 1986-87 edition is scheduled for publication in 1988. The AQUAREF database is searchable online through the CAN/OLE system of the Canada Institute for Scientific and Technical Information (CISTI) of NRC.

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